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Overview of Particle-In-Cell Simulations of Beam Spill - Cathode to Target

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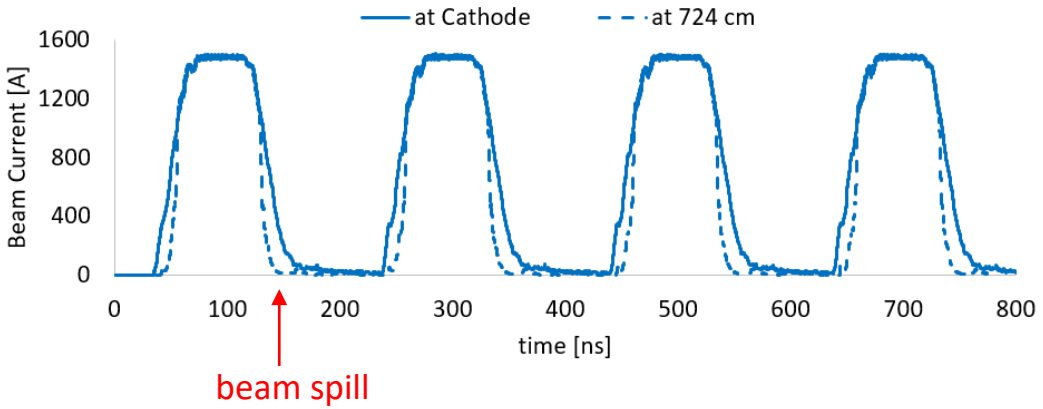
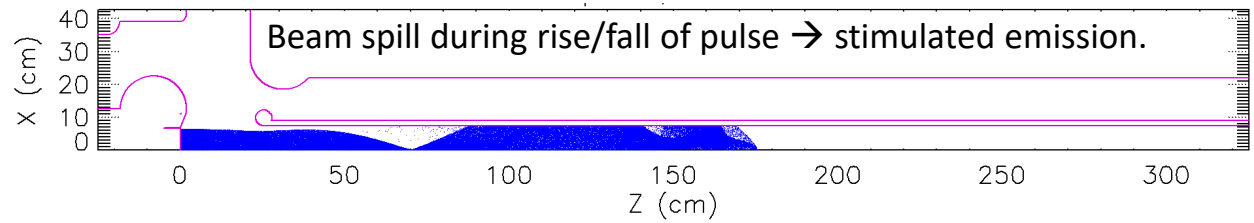
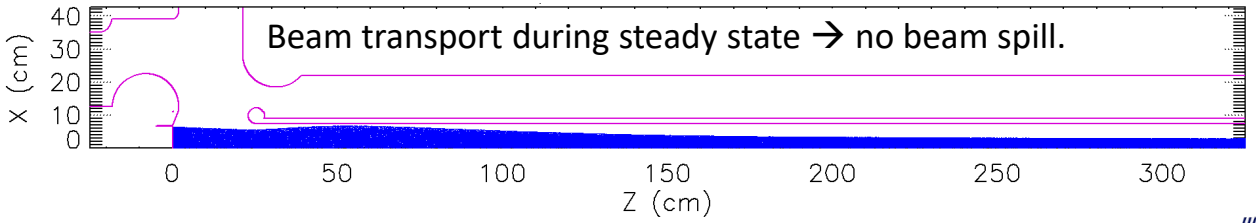
This is an overview of the set-up for beam spill simulations in the Injector.

- The injector was modeled using LSP in 2-D (r-z) coordinates.
- The 1:1 (push:pull) injector design was used (current as of Oct. 2020)
- Four TM5 pulses were used for the A-K electric potential.
- Electron stimulated emission of protons and singly ionized water were individually simulated.

Driven by TM5 Waveform







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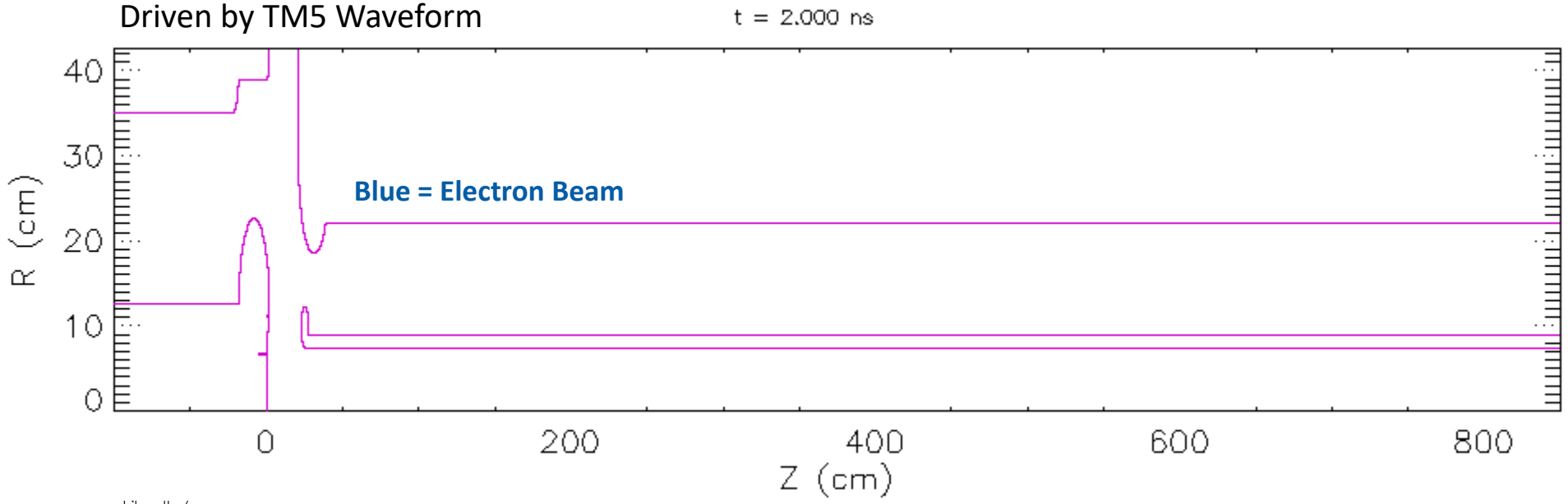
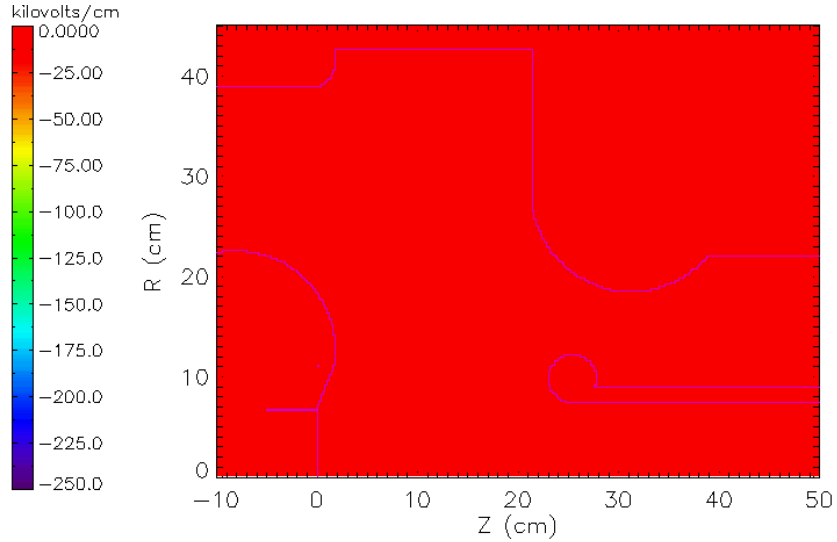
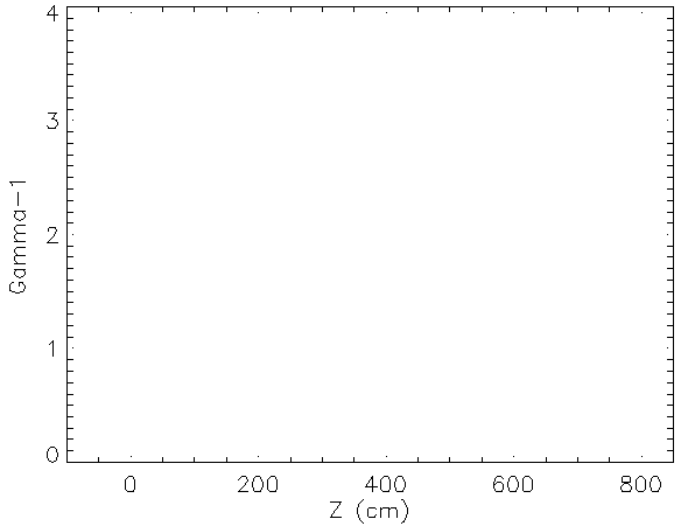
This slide shows electron transport, E-field in the A-K Gap, and beam energy.

Driven by TM5 Waveform

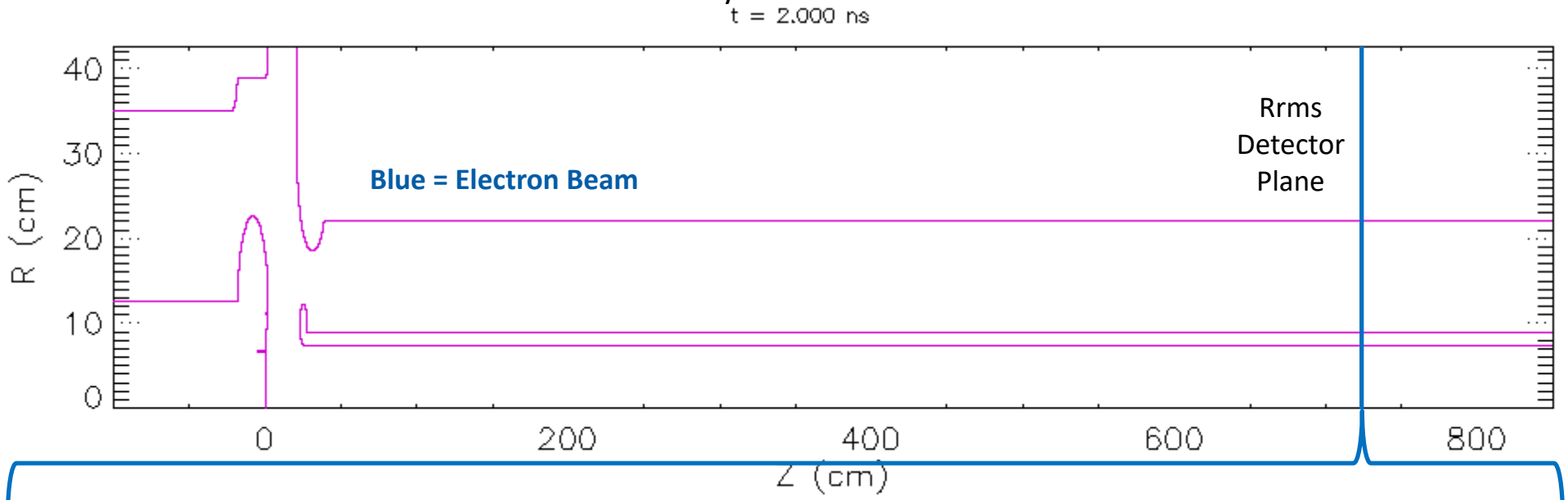


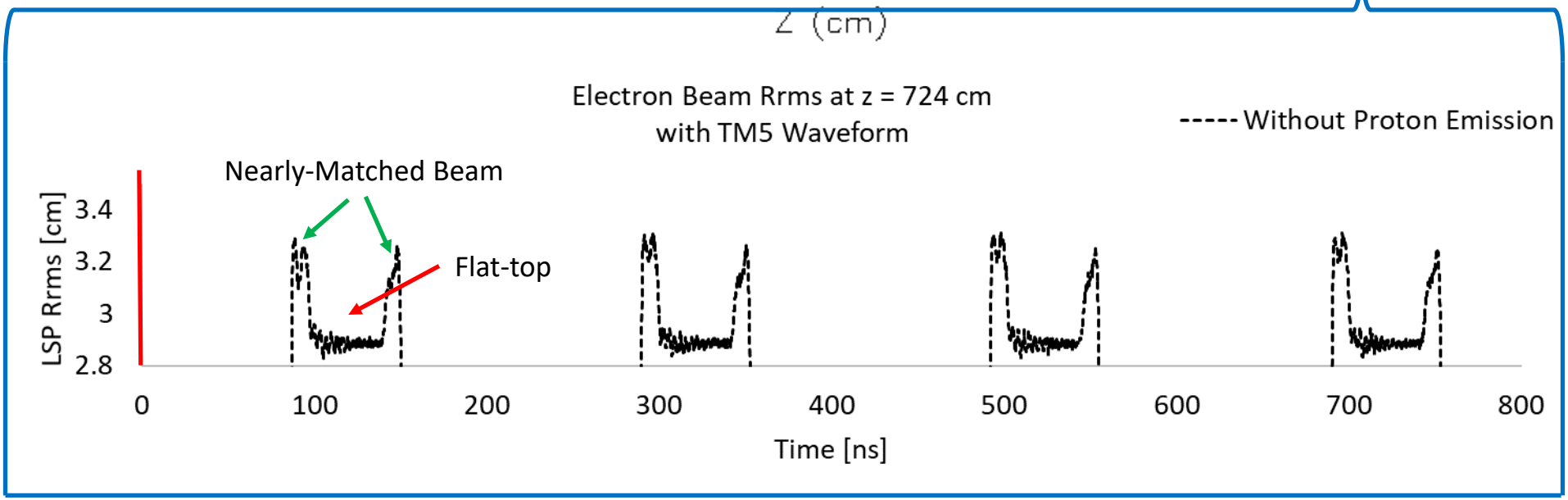




Nearly matched parts of the electron beam are transported.

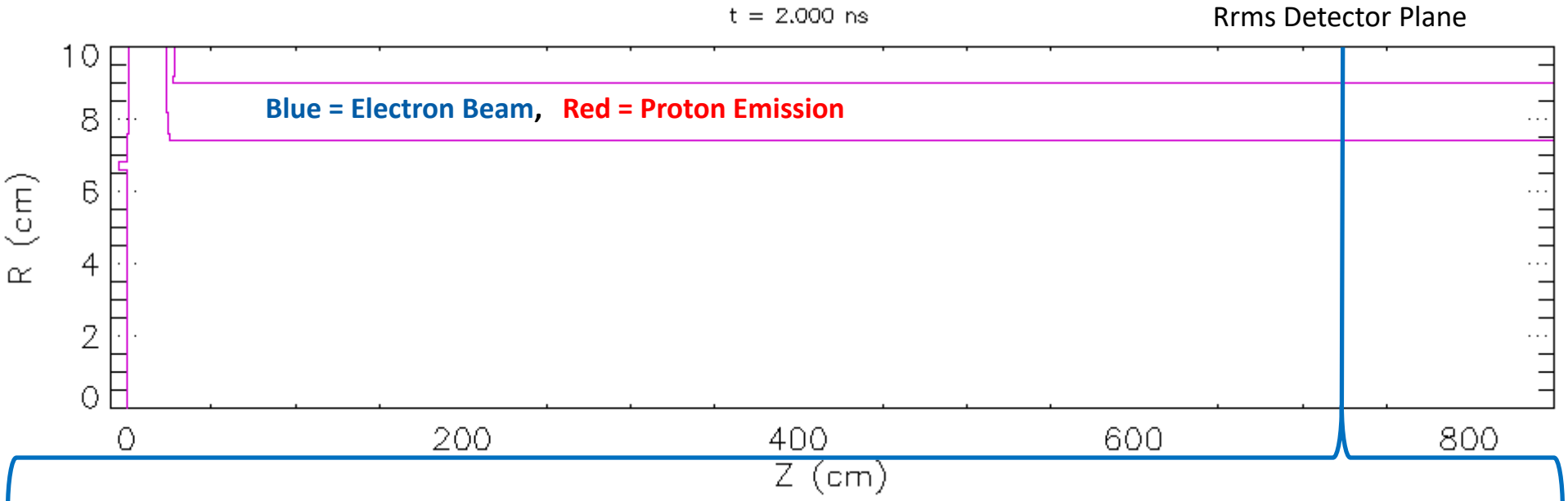
Driven by TM5 Waveform

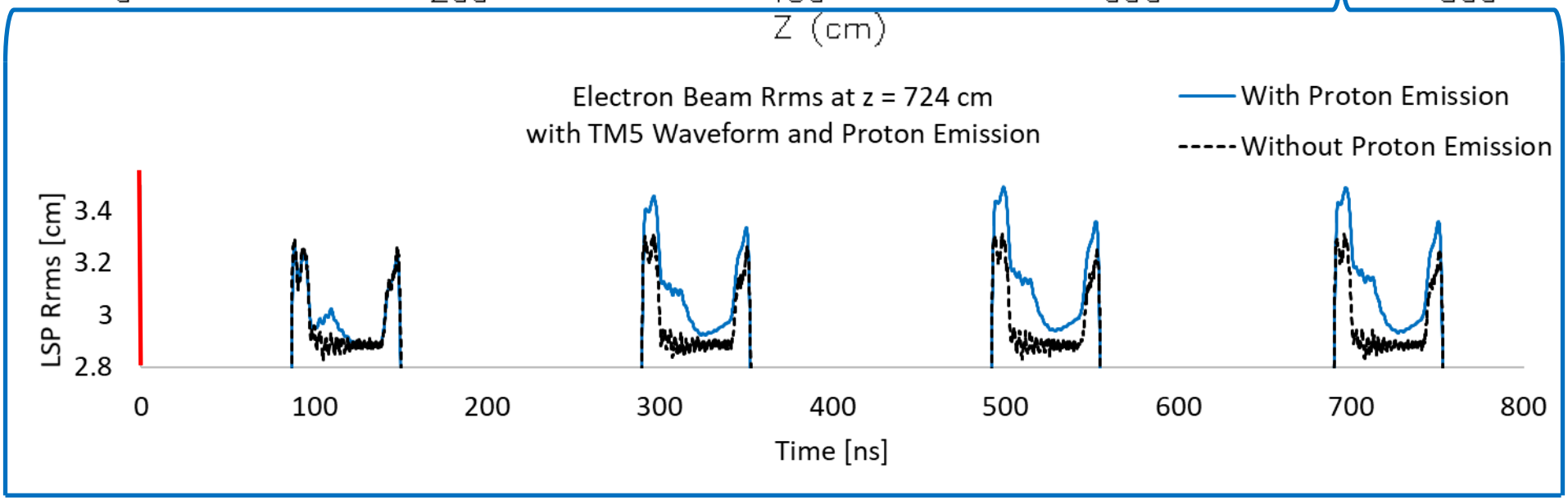




Electron Stimulated Emission of Protons

Driven by TM5 Waveform





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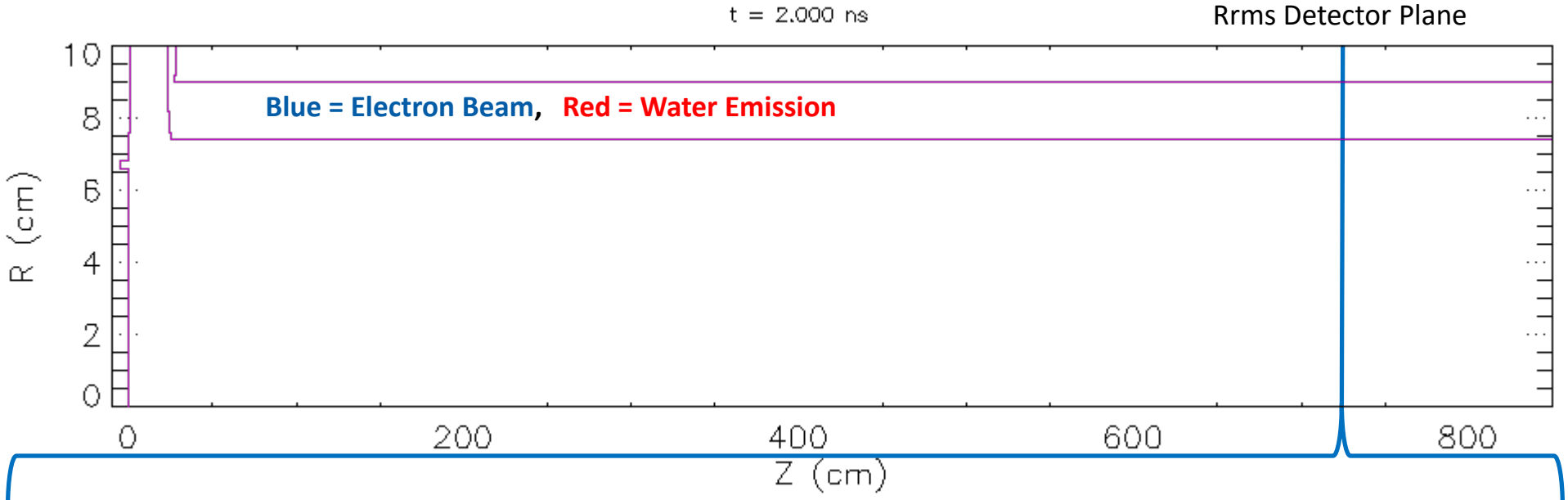
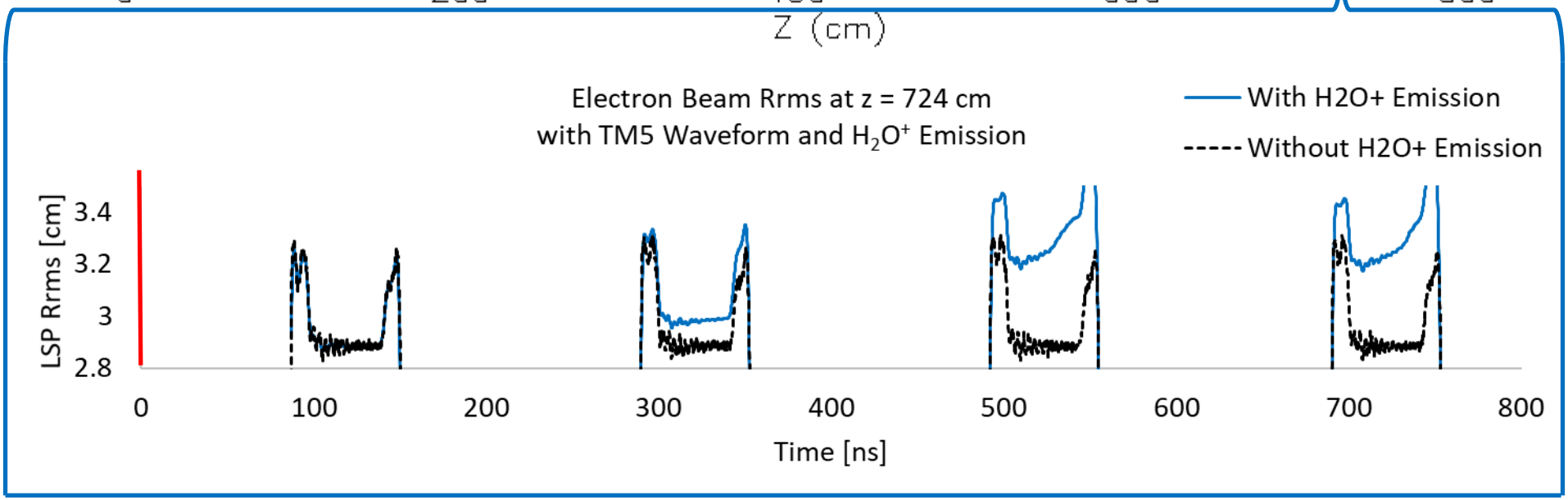
Electron Stimulated Emission of Singly Ionized Water

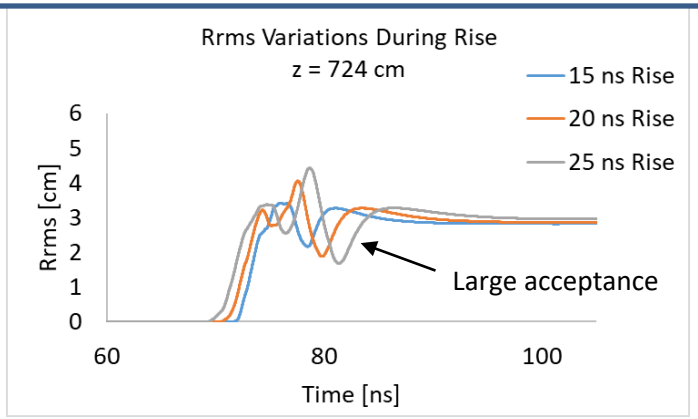
Driven by TM5 Waveform

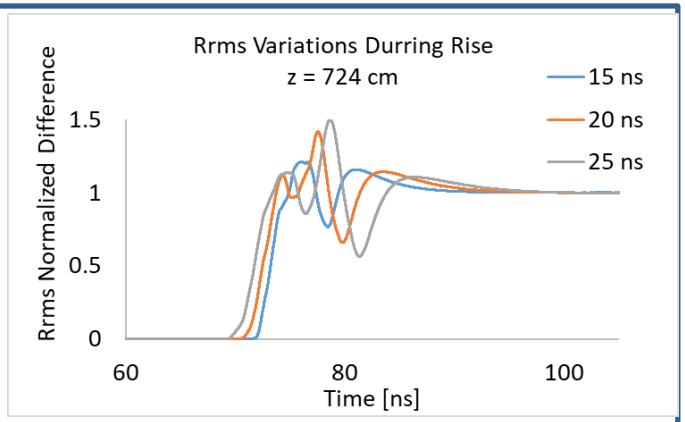




No Protons
3 Logistics Functions

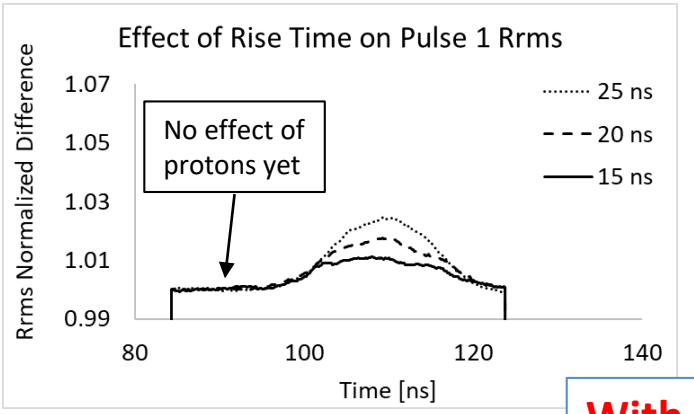
Rrms Variations:
- Short Time
- Large Amplitude

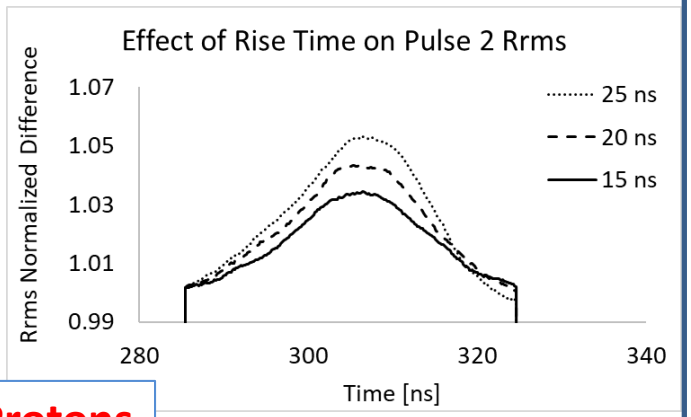




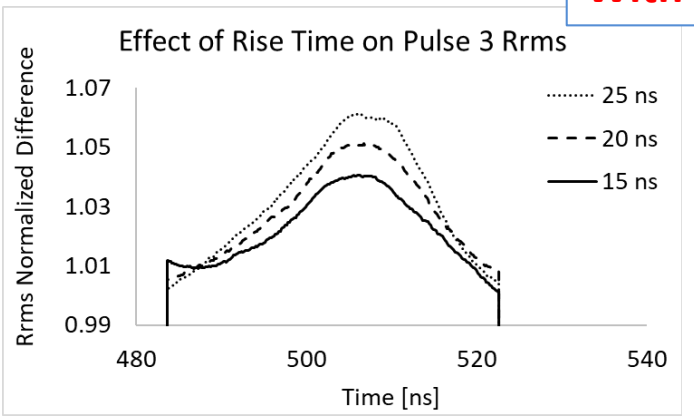
With Protons
Logistics Function

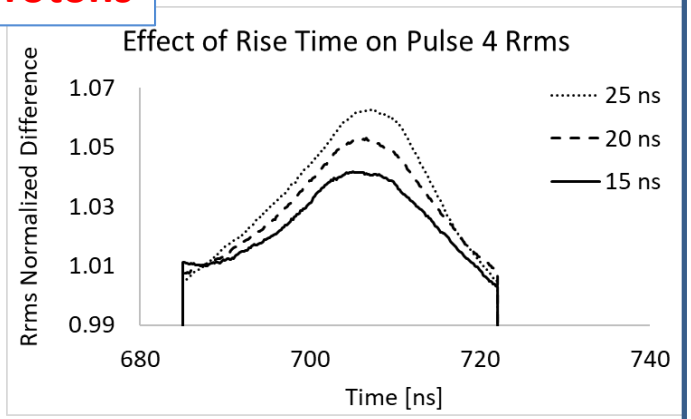
Rrms Variations:
- Long Time
- Small Amplitude





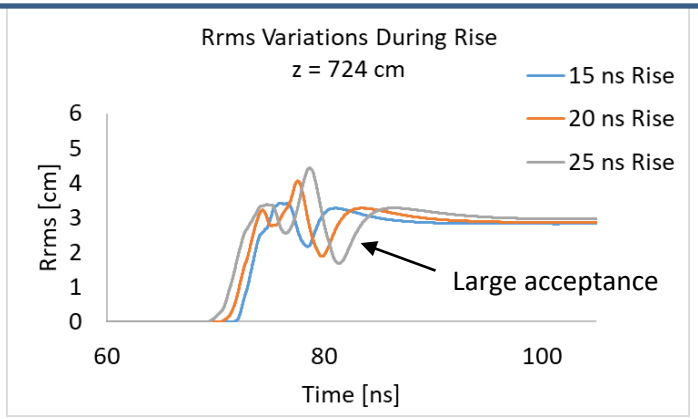
With Protons

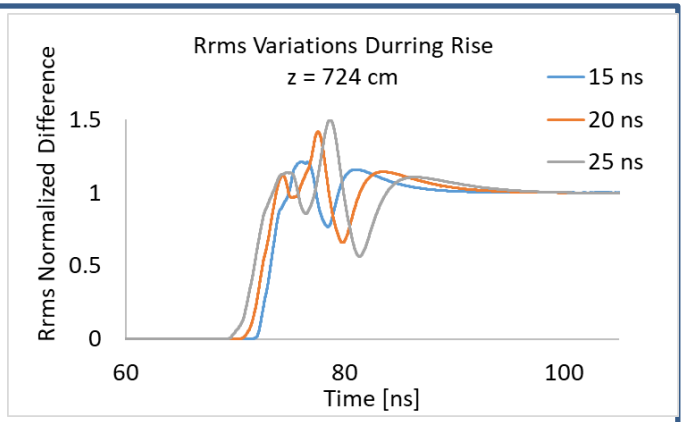




No Protons
3 Logistics Functions

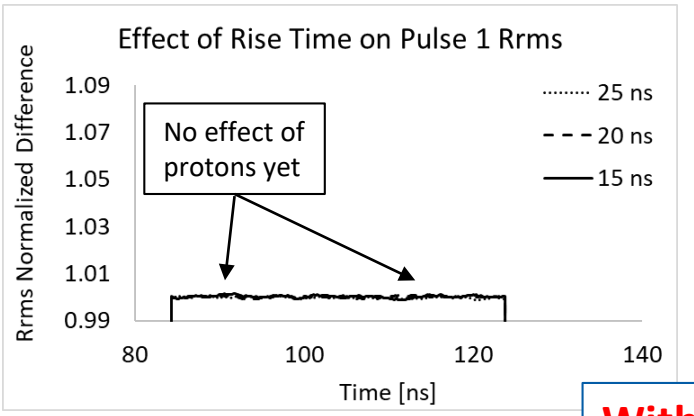
Rrms Variations:
- Short Time
- Large Amplitude

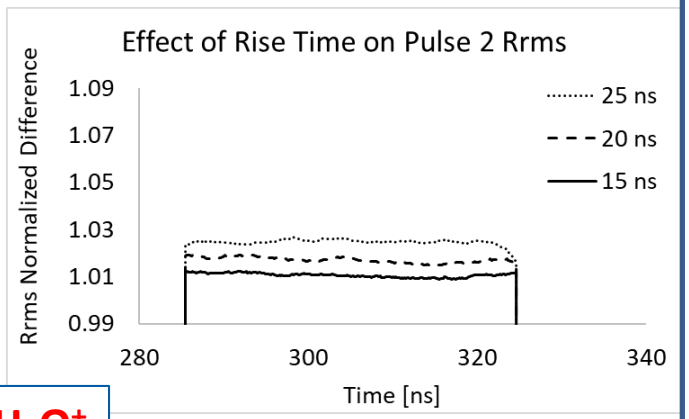




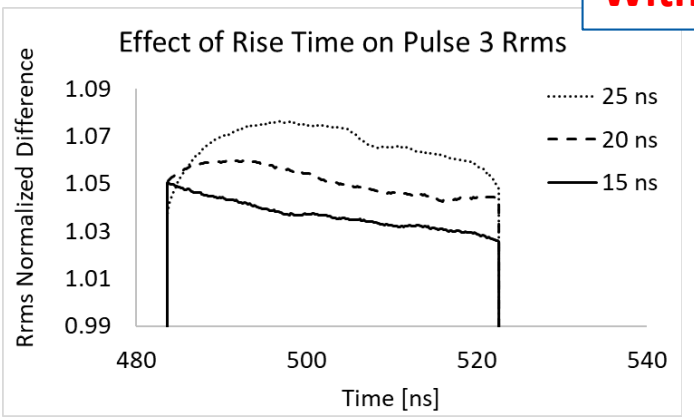
With H_2O^+
Logistics Function

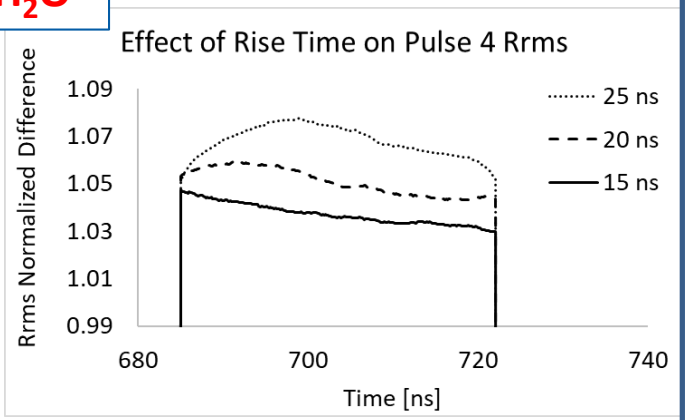
Rrms Variations:
- Long Time
- Small Amplitude



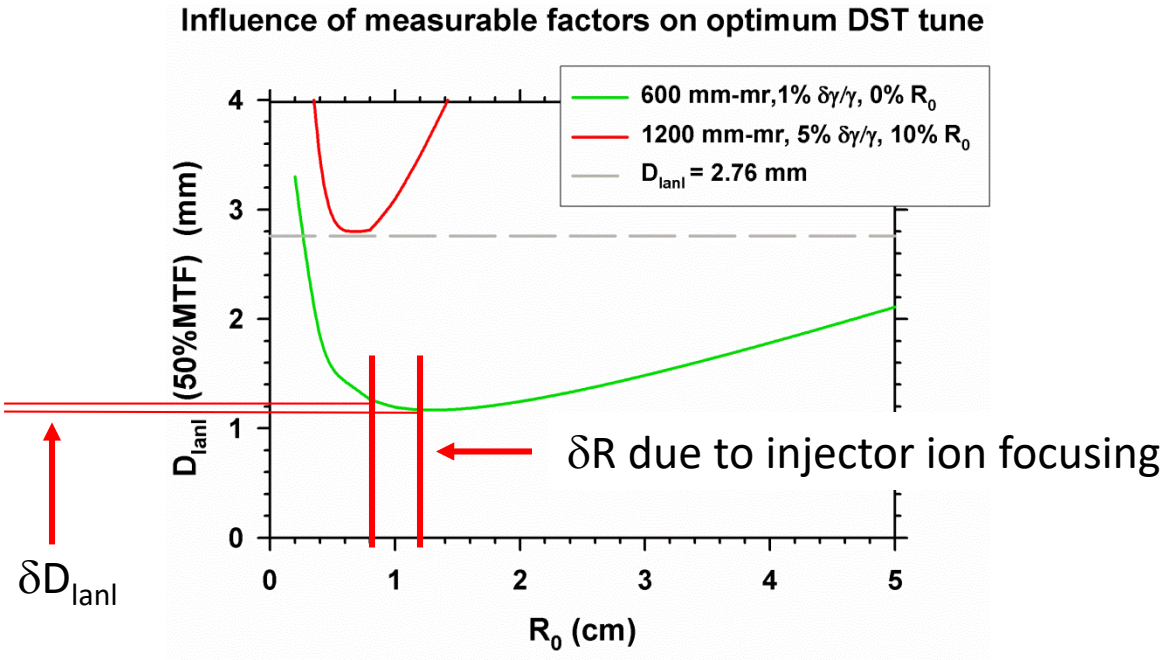


With H_2O^+





Carl Ekdahl [1] determined that spot size perturbation due to injector ion focusing can be determined from the perturbation to the beam size at the final focus input.



- Minimum spot achieved when each contributing effect is minimized.
- Diagnostics required for this are emittance, energy and high-frequency motion, at least.
- Spot size can be minimized by tuning the downstream transport for the optimum R_0.
- Target-ion focusing can be empirically accounted for by a multiplicative factor derived from time-resolved spot-size measurements.

[1] The information on this slide is from *Spot-size Enlargement due to Injector Beam Spill*, by Carl Ekdahl, presented at SWS Review, Dec. 2020.

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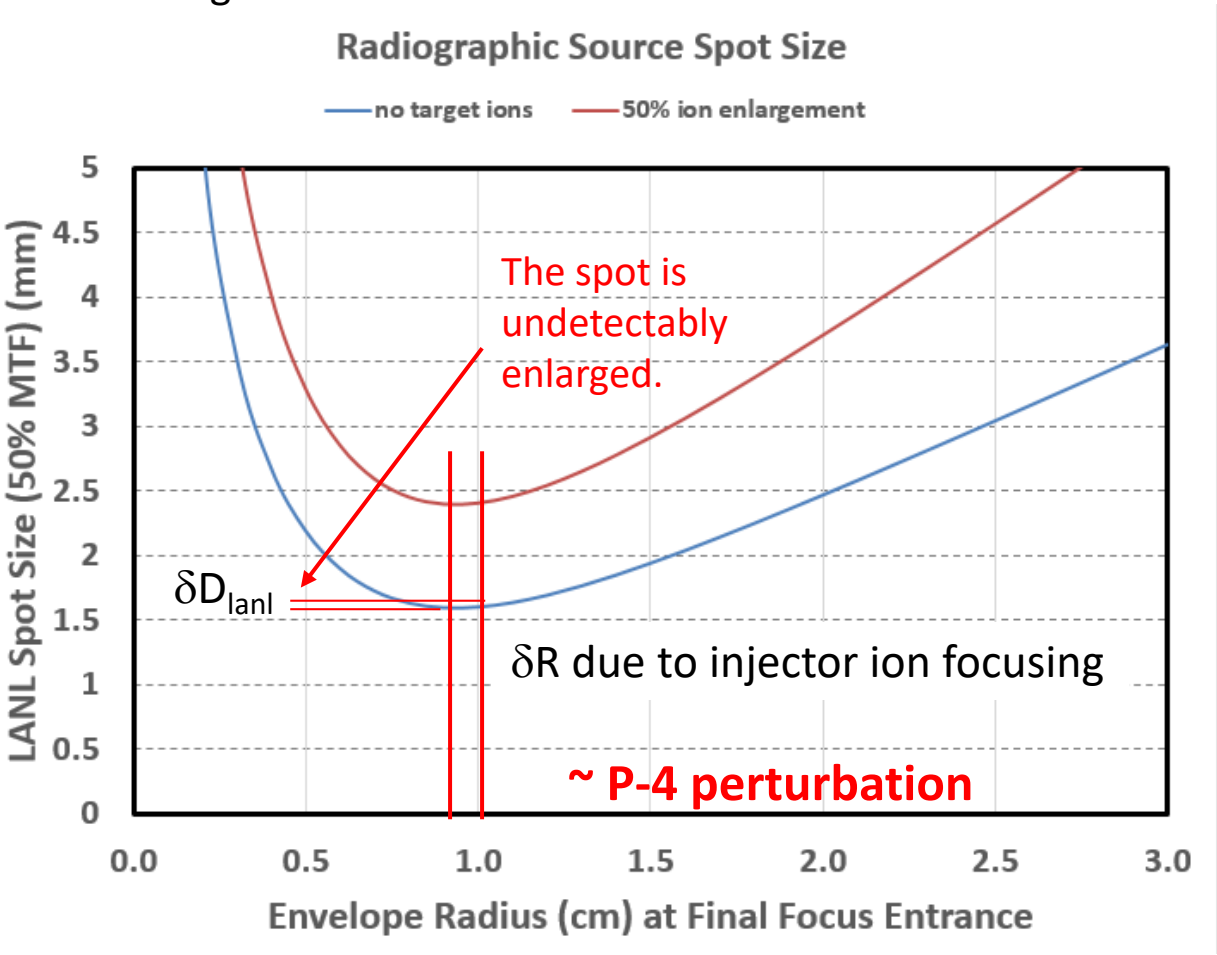
- Carl Ekdahl [1] performed an analysis using a DARHT-II final focus (f =25 cm , C_s = 0.0027132 cm^{-2}), ε_n=1000mm-mrad, dγ/γ =2%, motion =5% of R_0, based on a Scorpius tune.
- Carl used 50% enlargement due to ion focusing, based on Trent McCuistian's Axis-I data and taking credit for factor of two mitigation of the effect.



[1] The information on this slide is from *Spot-size Enlargement due to Injector Beam Spill*, by Carl Ekdahl, presented at SWS Review, Dec. 2020.

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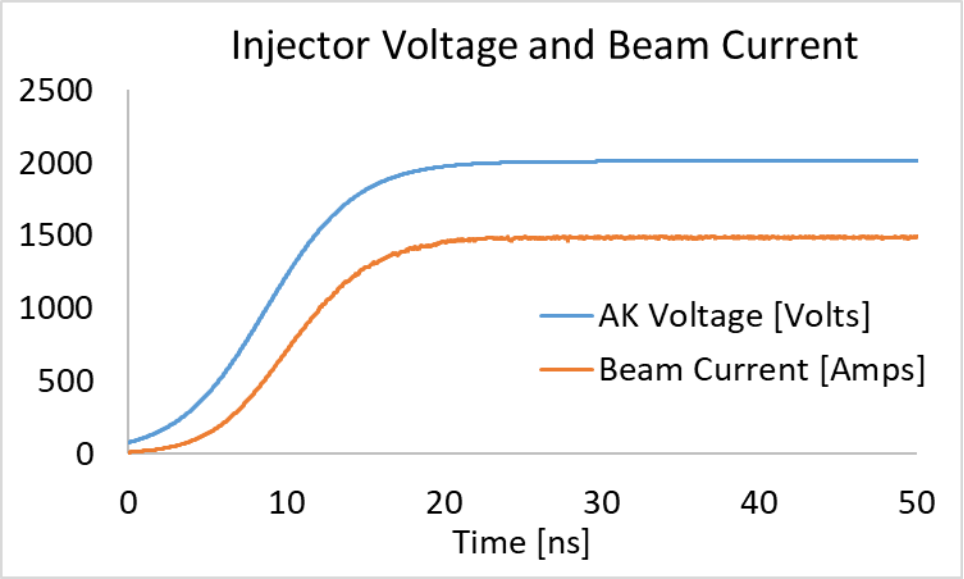
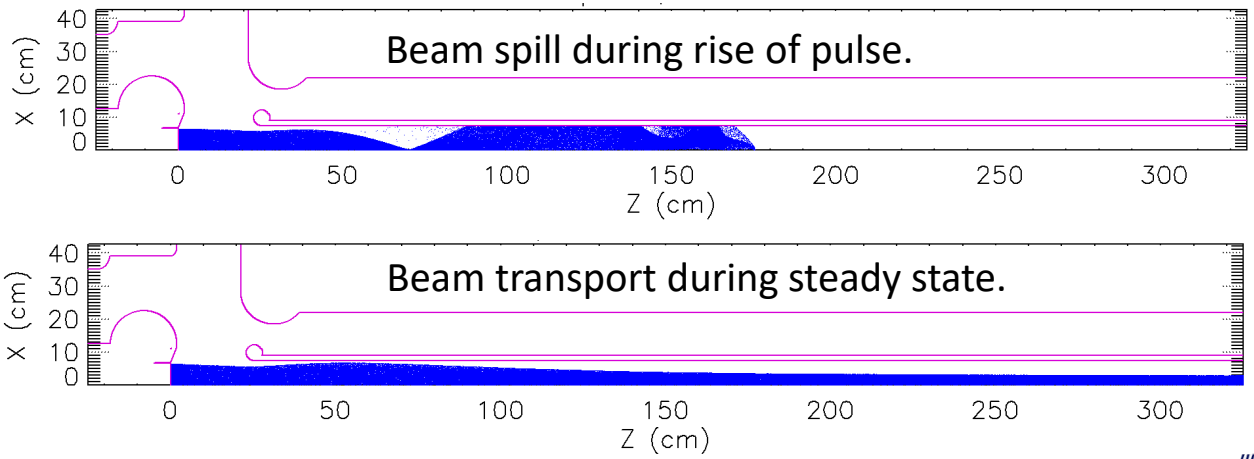
Next: Beam Spill in the Downstream Transport

This is an overview of the set-up for beam spill simulations of Downstream Transport.

- The injector was modeled using LSP in 2-D (r-z) coordinates.
- A logistics function was used for the A-K electric potential.
- The injector was ran to steady state, i.e. the pulse had a rise but no fall.
- Slices (r, dz) were extracted at z = 300 cm during the rise and steady state.

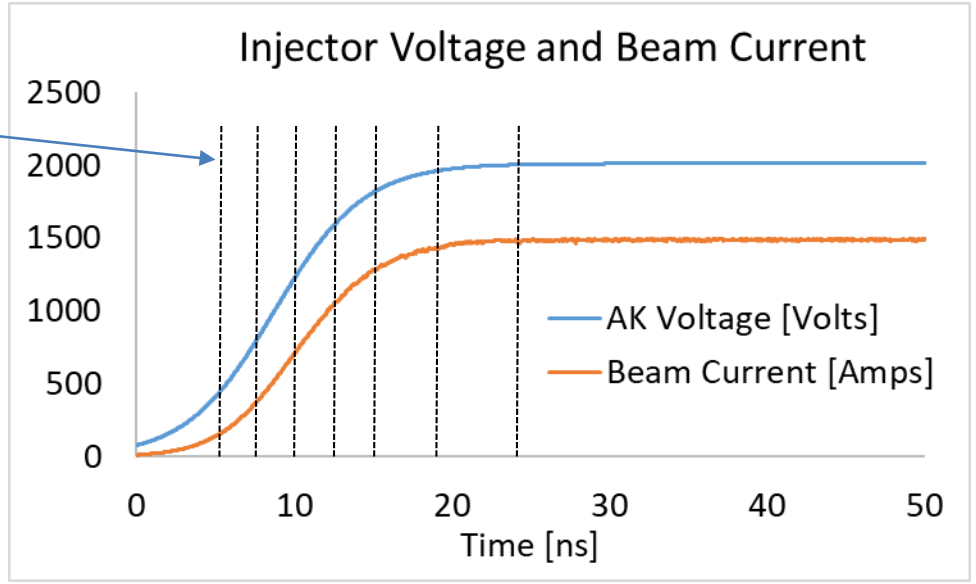


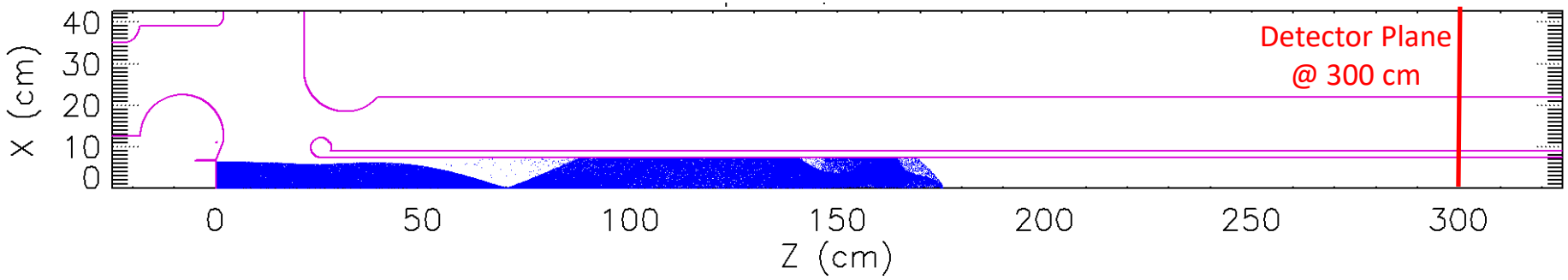


Electron positions and momentums are extracted at 300 cm during the rise and steady state.

Final Beam Energy	Beam Current at Cathode	Time of Birth at Cathode
20.77 MeV	95 Amps	4.8 ns
21.15 MeV	340 Amps	7.3 ns
21.57 MeV	675 Amps	9.8 ns
21.95 MeV	1030 Amps	12.3 ns
22.19 MeV	1268 Amps	14.8 ns
22.37 MeV	1445 Amps	19.8 ns
22.4 MeV	1486 Amps	24.8 ns

These are parameters of seven slices extracted at 300 cm during the rise and steady state of the beam current.





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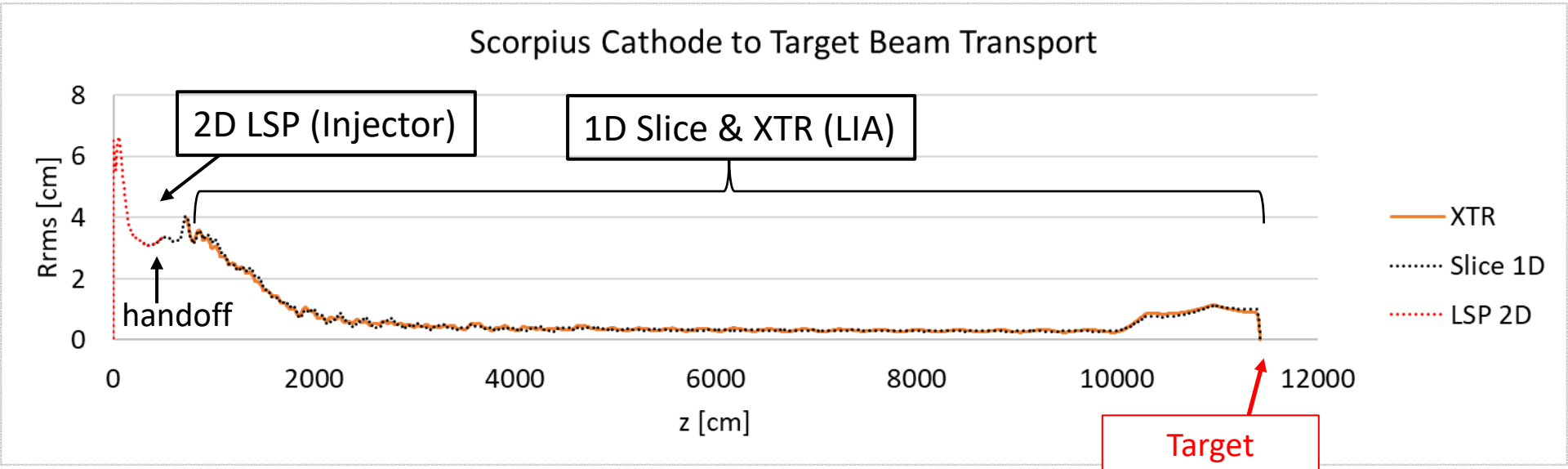
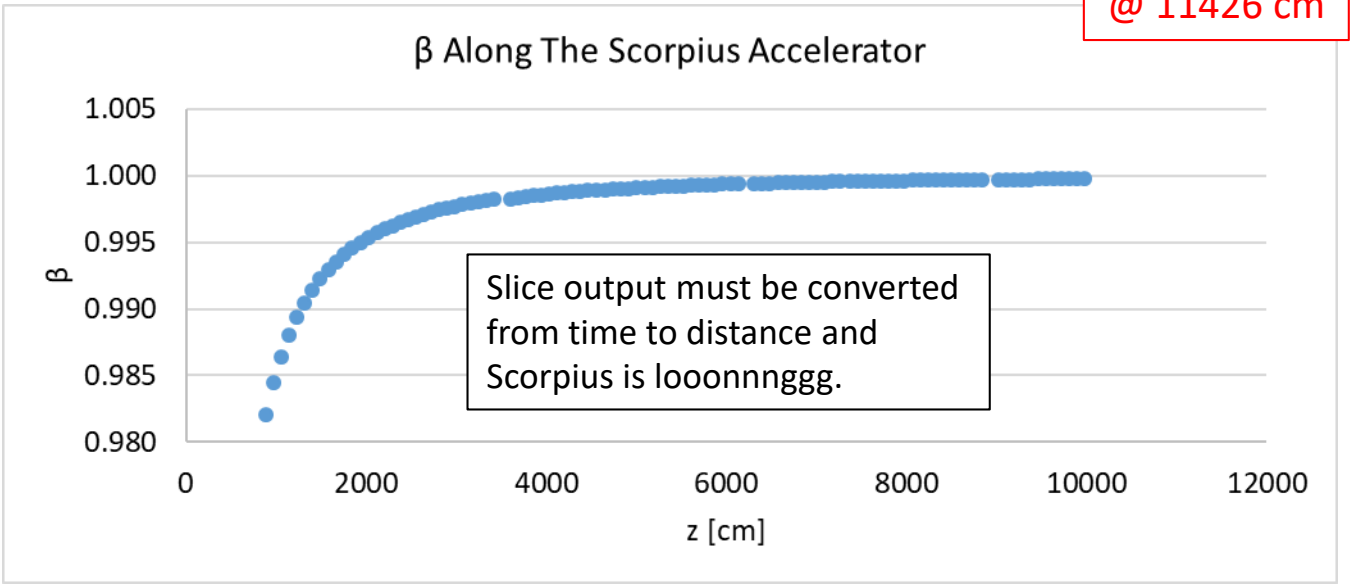
This slide shows the handoff from 2D LSP to 1D Slice (PIC) and XTR (envelope code).





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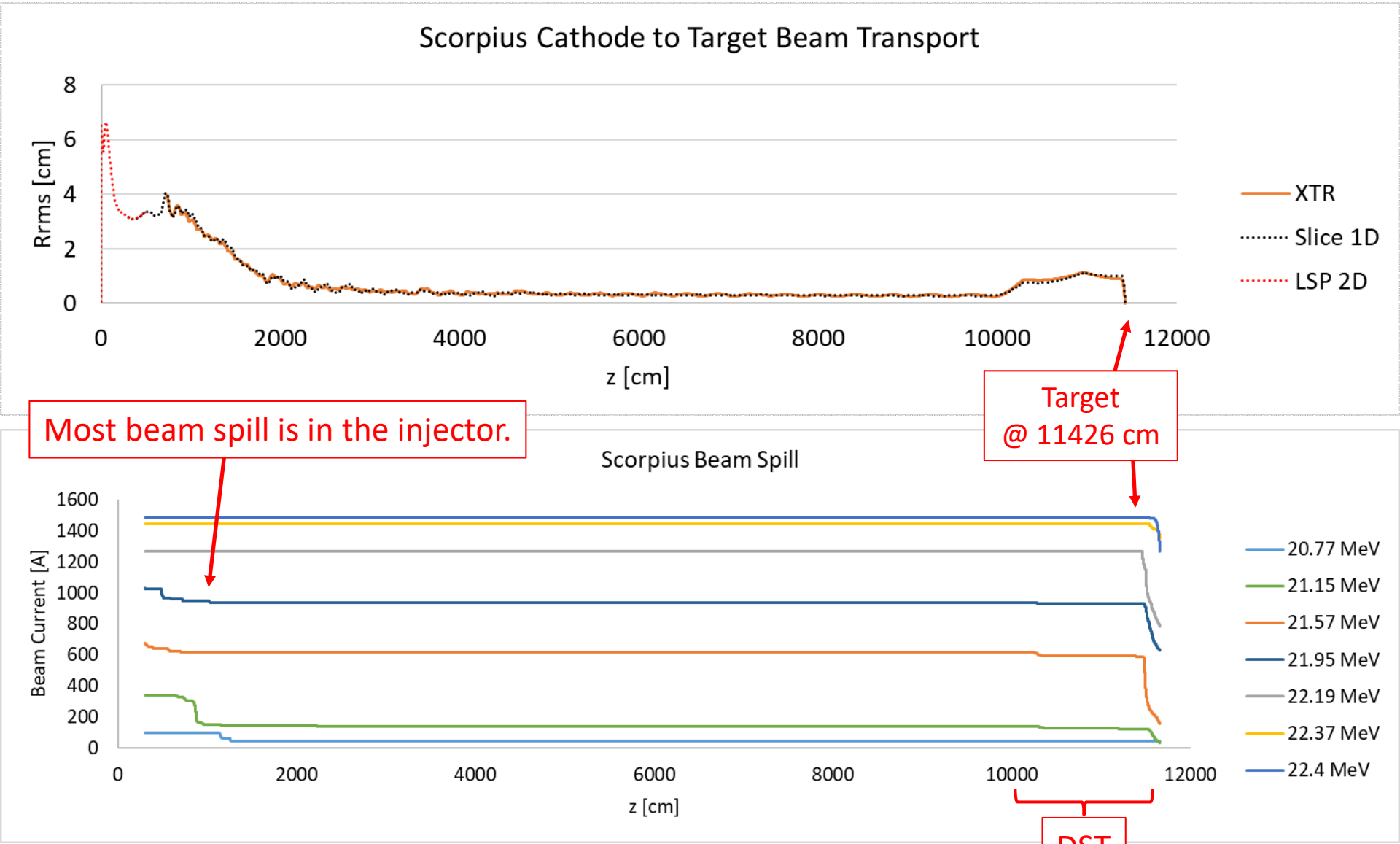
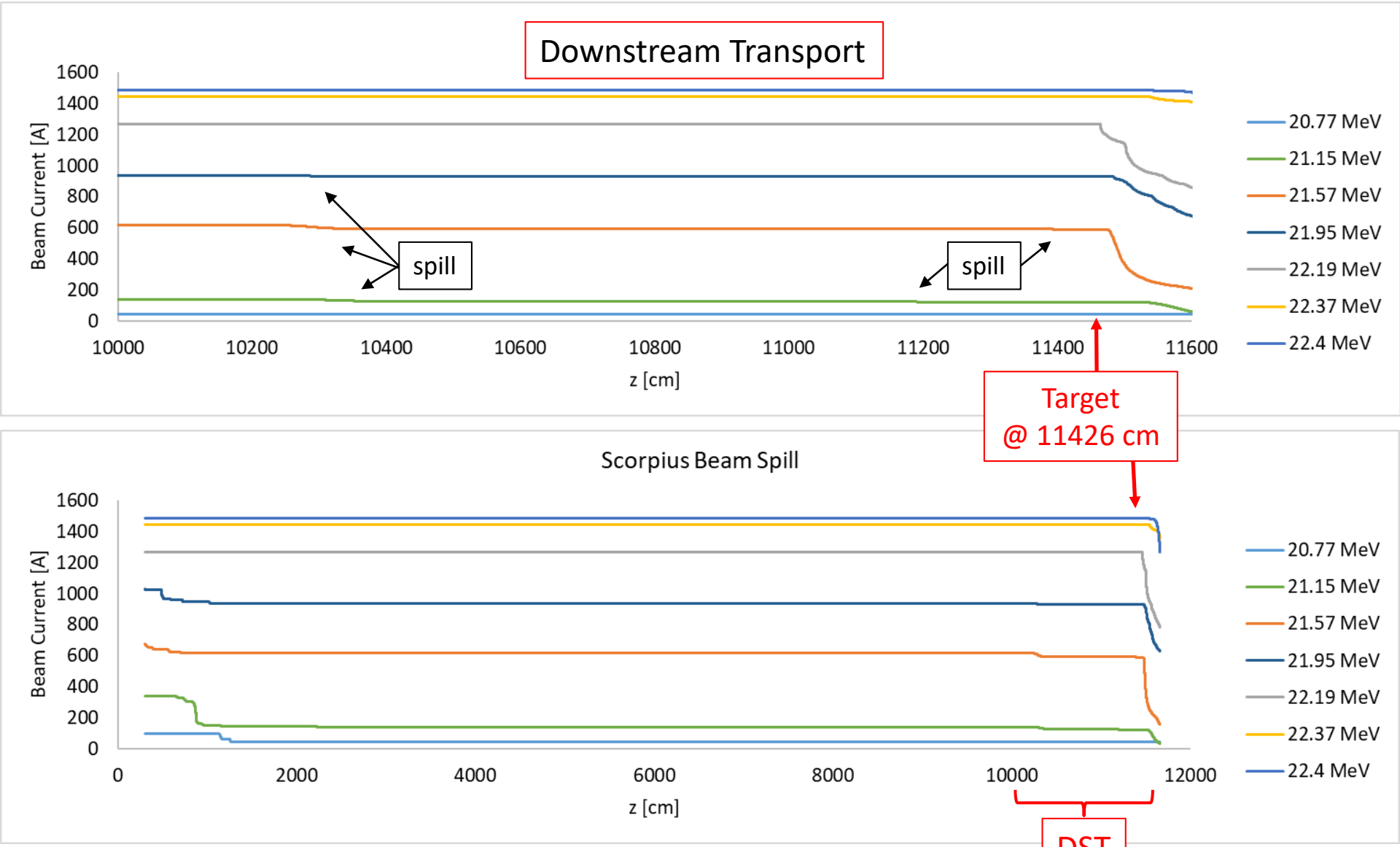
The beam spill occurs mostly in the injector and somewhat in the DST.

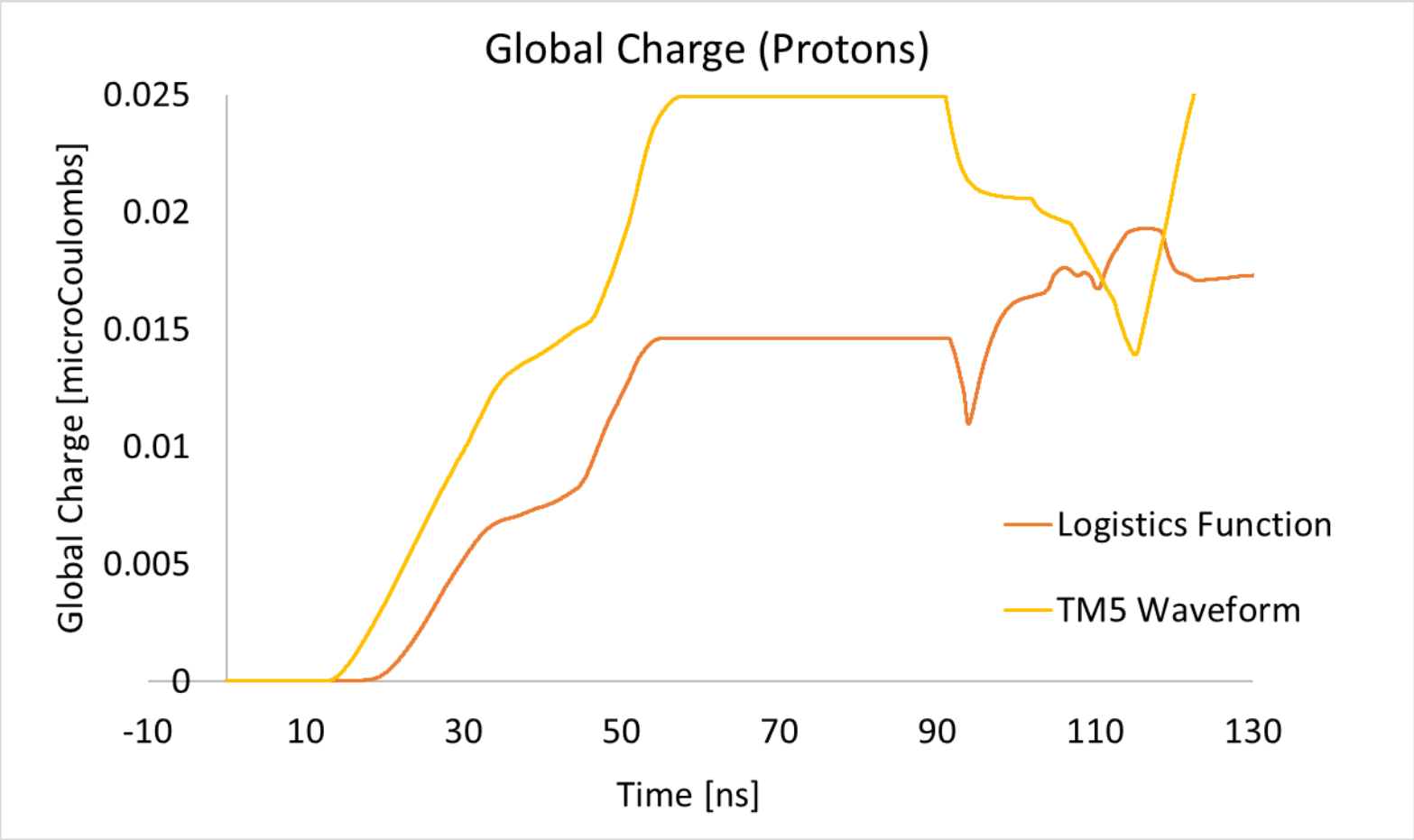


This slide magnifies the DST region to better show its beam spill.

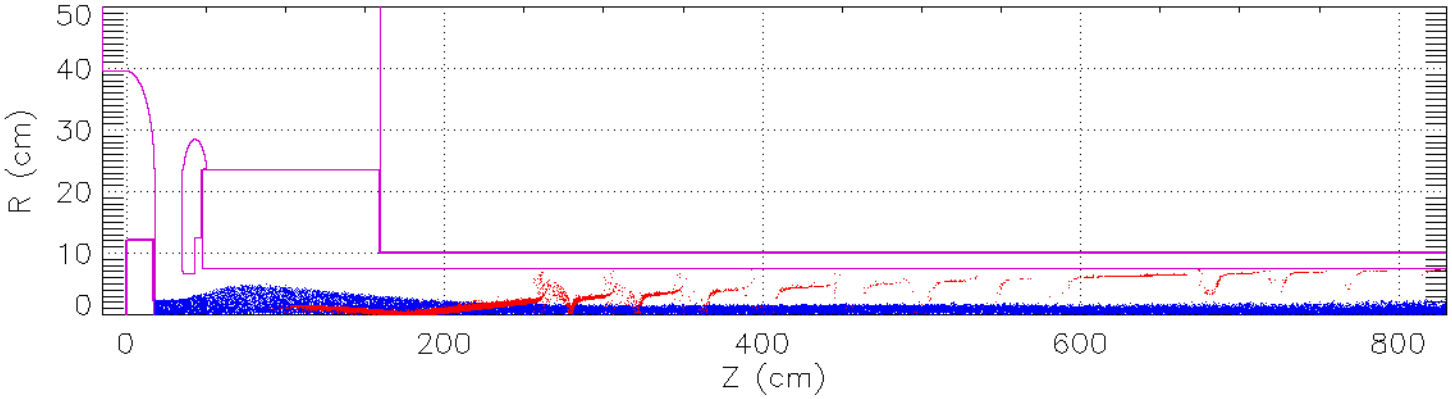


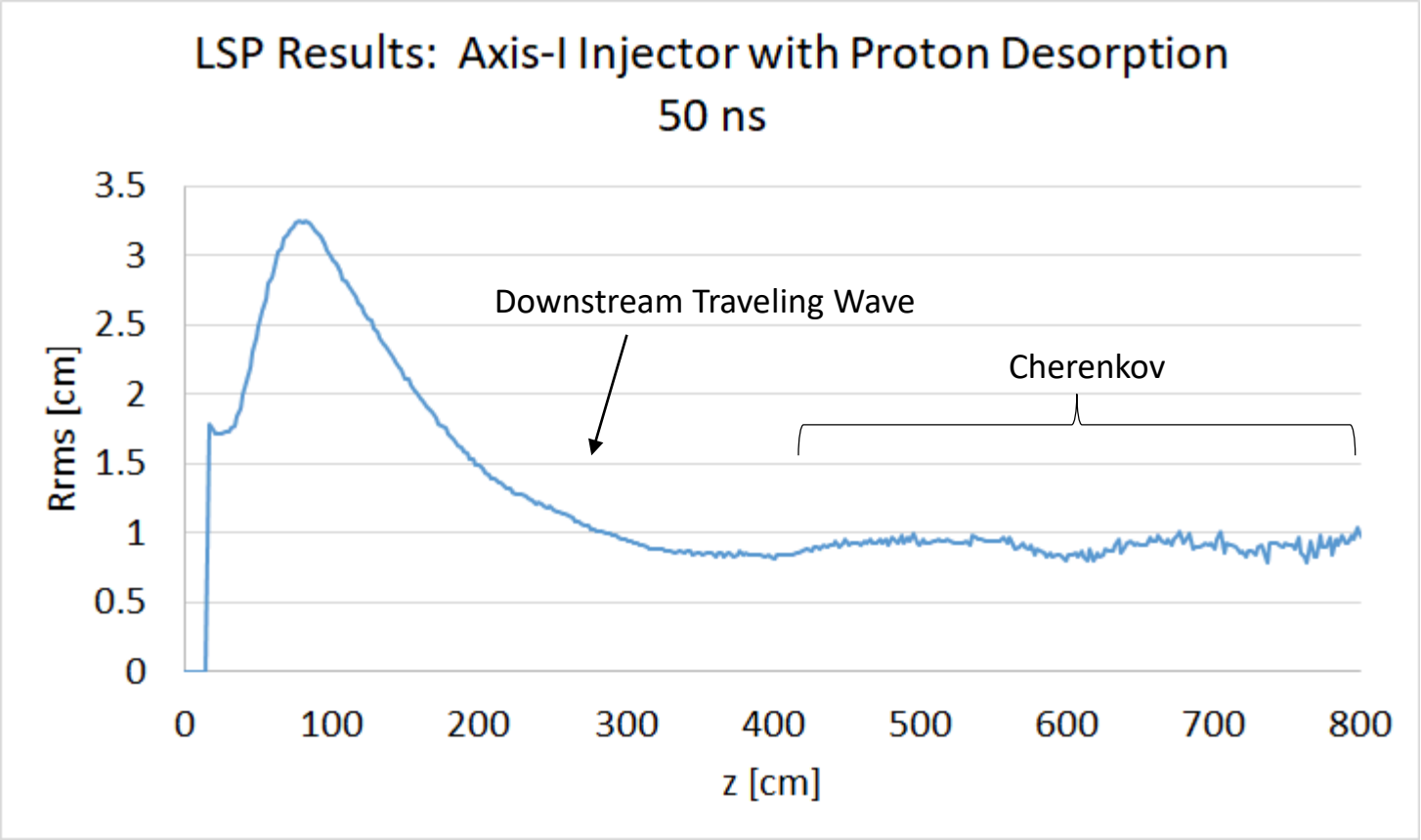
Backup Slides

This slide shows the difference between the number of emitted protons for A-K gap electric potentials driven by a TM5 waveform and a Logistics function.



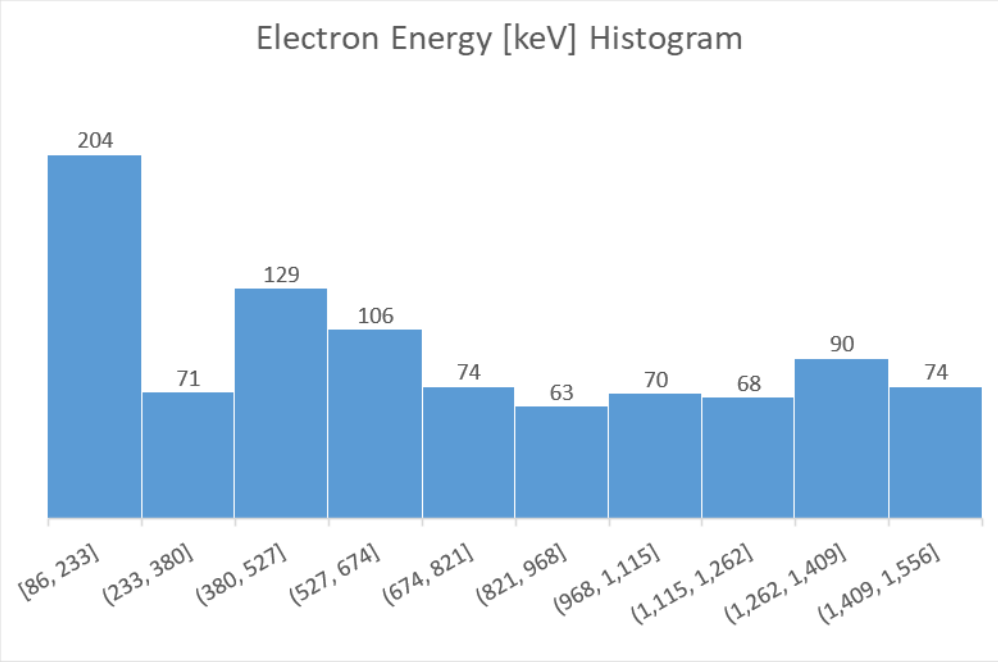
The Cherenkov (numerical) instability is noticeable after 400 cm in the Rrms plot (bottom plot).





Care must be taken to account for energy dependent cross-sections in LSP. (slide 1 of 3)

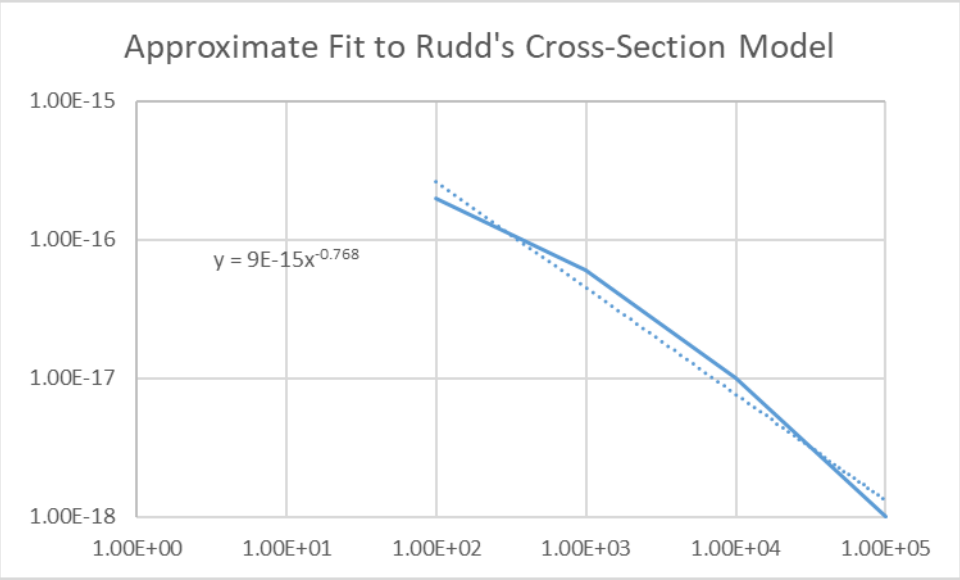
- LSP allows a single value, user entered cross-section for electron stimulated emission of ions.
- In reality, cross-sections are energy dependent.



(Ordinate) Electrons spilled during the beam pulse rise in the LSP simulation. (Abscissa) Energy bin in units of keV.

Care must be taken to account for energy dependent cross-sections in LSP (slide 2 of 3):

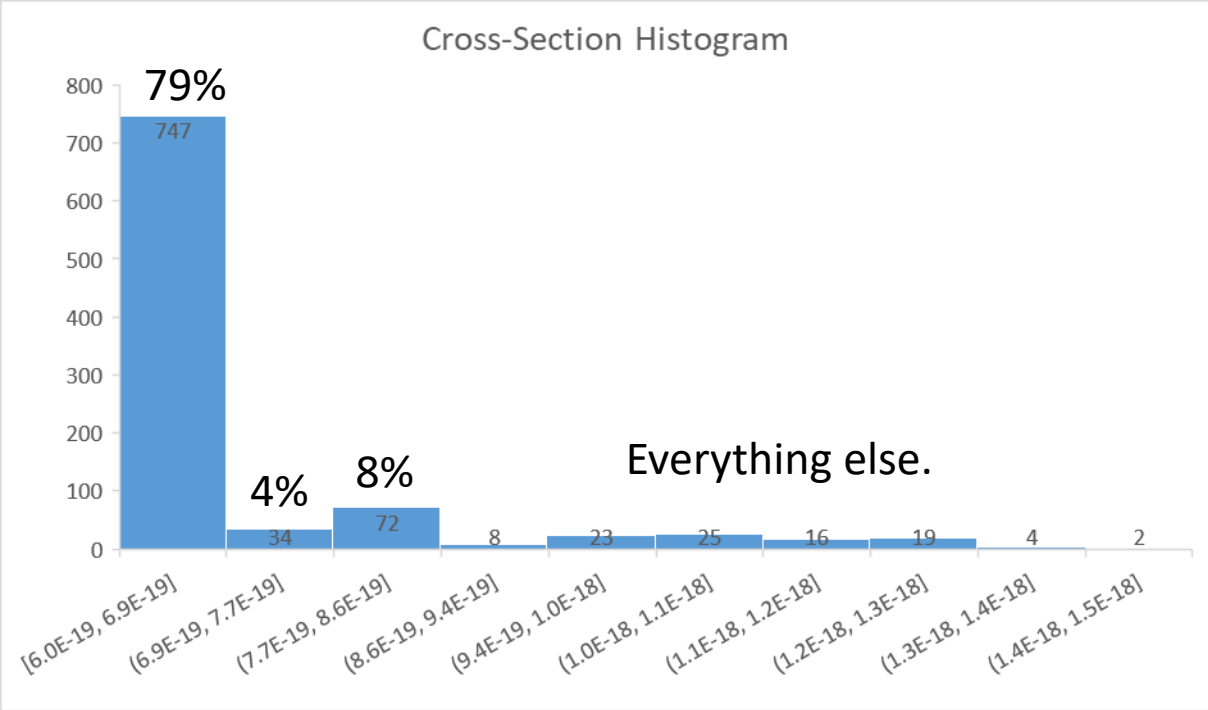
- Rudd's model provides a theoretical estimate of the energy dependent cross-sections.
- An approximate fit to Rudd's model provides a easy to use estimate of the theoretical estimate.



This image shows the quick approximation (dashed line) to Rudd's theory values (solid line) for energy dependent cross-sections.

Care must be taken to account for energy dependent cross-sections in LSP (slide 3 of 3):

- Number of electrons per energy bin are then converted to the number of electrons per cross-section bin.
- The average cross-section is 7.1×10^{-19} cm^2



(Ordinate) Electrons spilled during the beam pulse rise in the LSP simulation. (Abscissa) Cross-Section bin in units of keV.